Immersive and Non-Immersive VR Environments: A Preliminary EEG Investigation

没入型および非没入型 VR 環境：EEG の比較

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Abstract

Studies have attested to the potential of both immersive and non-immersive virtual reality environments in the health and medical field. However, side effects of using an immersive virtual reality environment such as those utilizing head mounted displays have been reported. The aim of this paper is to conduct a preliminary investigation into the EEG features of both immersive and non-immersive virtual reality environments. Results show distinct differences in the power magnitudes as well as in the power distributions between these two virtual reality environments.

Keywords: immersive environment, non-immersive environment, virtual reality, EEG, brain activity power spectrum

Introduction

Virtual reality has been trumpeted by technology pundits as the next big thing in digital entertainment. There has been much hype around virtual reality (VR) headsets or head-mounted displays such as the *Oculus Rift*, and the *Sony PlayStation VR*. Virtual reality (VR) is defined as an artificial environment which is experienced through sensory stimuli (as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment [1]. VR can be classified as either immersive or non-immersive. An immersive VR environment is defined as one where a physical presence is perceived in an artificial or non-physical world. Users of VR headsets experience a visceral feeling of being in a digitally simulated world. On the other hand, a non-immersive VR environment is one where a user does not experience a sense of presence that can only be perceived in an immersive environment. Thus, in this paper, VR using head-mounted displays fall into the category of an immersive VR environment, while first-person-view videos viewed on a desktop or an iPad or Android tablet are considered as non-immersive VR.

The applications of virtual reality, whether immersive or non-immersive, are not limited to games and entertainment. In fact, VR applications in the health and medical field have been reported in literature [2–6]. With the availability of head mounted displays, the potential for novel applications dramatically increases.

However, side effects of using immersive VR such as headaches, nausea, and disorientation have been reported [7–8]. This sort of cyber sickness becomes an obstacle to the development of VR applications. This study aims to conduct a preliminary investigation of EEG features in both immersive VR and non-immersive VR environments.

Methods

The immersive VR environment platform consisted of a *Google cardboard*, a low-cost head mounted display that utilizes an *Android* phone to render a VR environment. See Figure 1. The VR software used was the *Roller coaster cardboard VR* developed by *Area 1* which can be downloaded from *Google Play*. The screen images of this VR software during play are shown in Figure 2.

The non-immersive environment platform consisted of an *iPad* tablet with which a first-person-view video of a roller coaster ride was viewed. Figure 3 shows a screenshot of the *Leviatan* roller coaster in Canada [9].

EEG signals were collected with a 5 channel wireless EEG headset with a sampling rate of 128 samples per second per channel. Two reference sensors are linked to the left mastoid. The screen image of brain activity showing

Fig. 1. Google Cardboard VR Headset

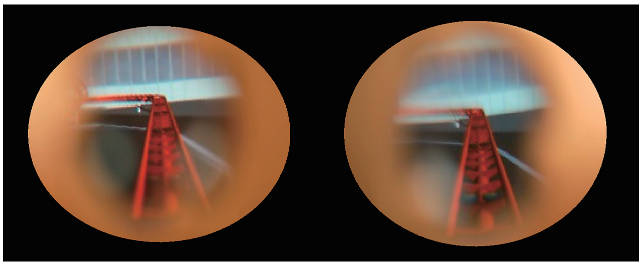
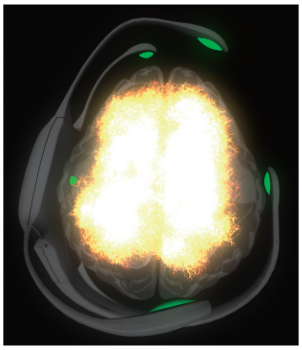


Fig. 2. Screen images of Google Cardboard with an Android phone running a Rollercoaster VR software.

Fig. 3. Screenshot of a front-seat rollercoaster ride
(Courtesy of Youtube: https://www.youtube.com/watch?v=_0ASWKwQwzE)



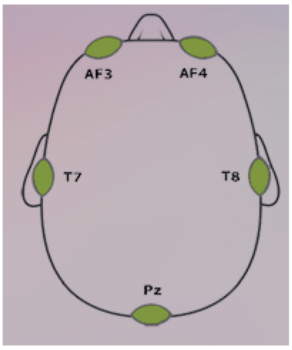


Fig. 4. Screen image of brain activity and electrode placement locations (AF3: CH1, T7: CH2, Pz: CH3, T8: CH4, AF4:CH5)

the EEG headset and the location of electrodes are shown in Figure 4. Channels 1 to 5 represent locations AF3, T7, Pz, T8, and AF4, respectively. AF3 and AF4 are in the frontal cortex, T7 and T8 in the parieto-temporal, and Pz in the occipital regions.

In this study, the author himself served as the lone test subject. The test subject's EEG signals were taken for both immersive and non-immersive VR environments. Raw EEG data was processed with *EEGLAB* developed by the Swartz Center for Computational Neuroscience at the University of California San Diego. EEG data for each channel was plotted, and artefacts such as those caused by eye blinks were visually identified and rejected. Brain activity spectrum plots were made for 2.0, 4.0, 8.0, 13.0 and 22.0Hz. The EEG signals were then separated into different frequency bands (4−8Hz) theta, (8−13Hz) alpha, and (13−30Hz) beta using an FIR digital bandpass filter.

Results and Discussion

The brain activity spectrum otherwise called the power spectral density or power spectrum for an immersive VR environment (IVR) is shown in Figure 5. It shows the strength of the energy variations as a function of frequency. Here, the colored traces represent the activity spectrum of each data channel. Trace lines for the different channels are as follows: red for CH1, green for CH2, blue for CH3, black for CH4, and yellow for CH5. Scalp maps which indicate the signal power distributions are plotted for 2.0, 4.0, 8.0, 13.0 and 22.0Hz frequencies. Figure 6 shows the brain activity spectrum and scalp maps for a non-immersive VR environment (NIVR). Generally, in both figures, the power for each channel is greater at the start and decreases as the frequency increases around 10−15Hz. For all frequencies plotted, IVR has greater power magnitudes compared to that of NIVR, except for CH3 (Pz) with three peaks at around 18, 23, and 27Hz. Although artefacts were visually removed previous to analysis, further examination is necessary to determine whether these are really artefacts. The most significant difference in the scalp maps is at the 13.0Hz frequency, where greater activity is concentrated at the frontal area for IVR, but is concentrated at the occipital area for NIVR.

The brain activity spectrums for the theta frequency (4−8 Hz) for both IVR and NIVR are shown in figure 7. Line channel traces are rather dispersed for IVR, but are rather bundled closer for NIVR. For IVR, CH1 (AF3), CH4 (T8), CH5 (AF4), at the frontal, at the right parieto-temporal, and at the occipital regions have higher power magnitudes than those of NIVR. Power distributions shown as scalp maps

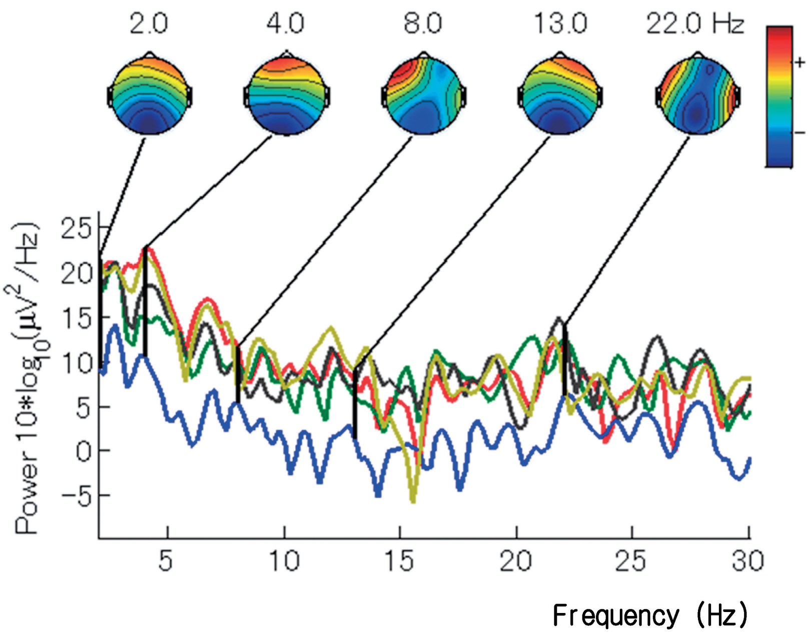


Fig. 5 Brain Activity Spectrum: immersive VR environment (IVR)
Line legends: (red: CH1, green: CH2, blue: CH3, black: CH4, yellow: CH5)

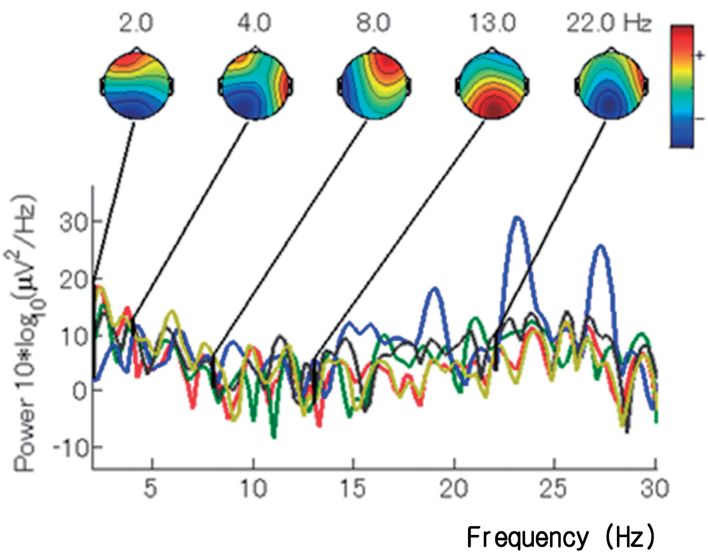
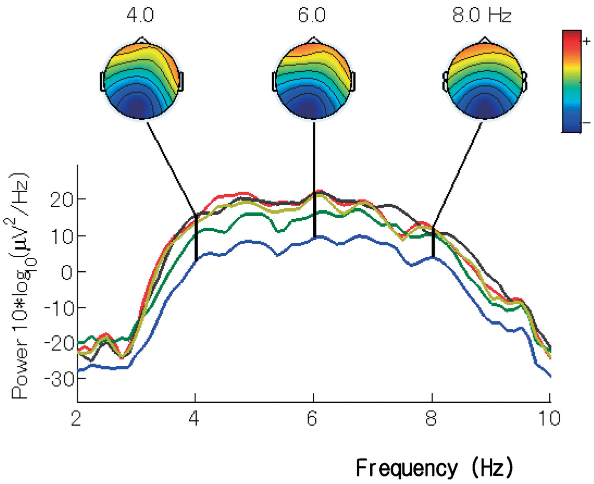


Fig. 6. Brain Activity Spectrum: non-immersive VR environment (NIVR)
Line legends: (red: CH1, green: CH2, blue: CH3, black: CH4, yellow: CH5)

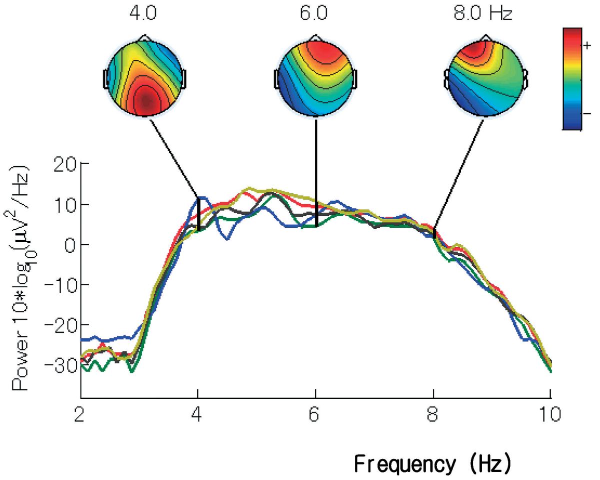
indicate greater concentration at the frontal areas for both IVR and NIVR, except those at 4.0Hz. A higher power spectrum for IVR may be attributed to the increase of theta waves during spatial navigation of IVR environments.

The brain activity spectrums for the alpha frequency (8–13 Hz) for both IVR and NIVR are shown in figure 8. Although line channel traces are rather bundled closer than those in the previous figure, CH3 shows generally lower power magnitudes for IVR than that of NIVR. It is worth further investigation to determine whether this difference is caused by weak signals at CH3 brought about weak conductivity at the AF4 electrode. The power magnitudes at the 8–9Hz frequency band are higher for IVR than those for NIVR. This may suggest that at this frequency band, slight drowsiness may have caused greater alpha power during spatial navigation of IVR. The concentration or power distribution for 8.0, 10.0, and 13.0Hz frequencies are distinctly different for both cases.

Figure 9 shows the brain activity spectrums for beta frequency (13–30Hz) for both IVR and NIVR. There are no

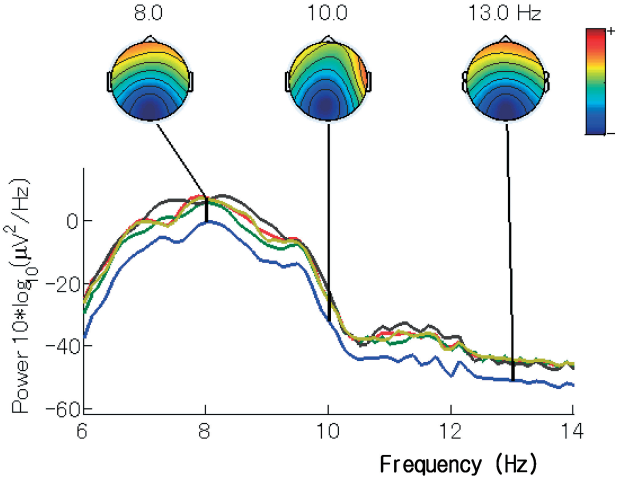


a) Immersive VR environment
(IVR)

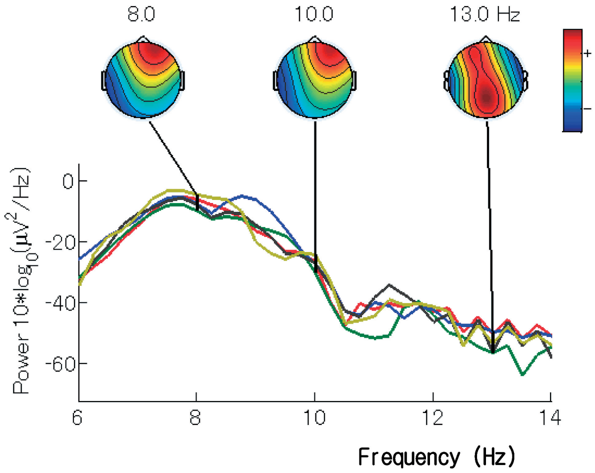


b) Non-immersive VR environment
(NIVR)

Fig. 7. Brain activity spectrum in the theta frequency
Line legends: (red: CH1, green: CH2, blue: CH3, black: CH4, yellow: CH5)

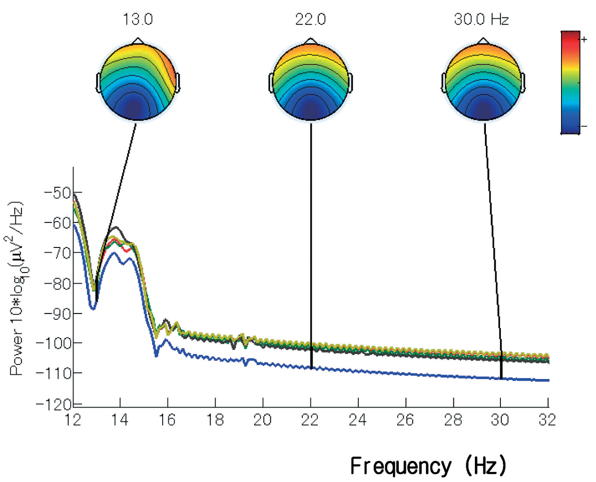


a) Immersive VR environment
(IVR)

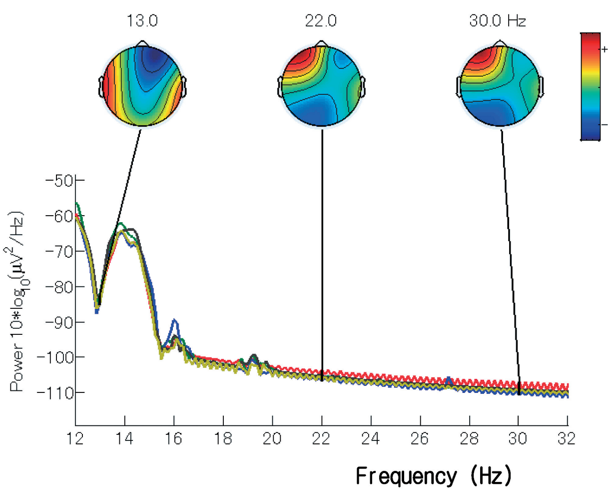


b) Non-immersive VR environment
(NIVR)

Fig. 8. Brain activity spectrum in the alpha frequency
Line legends: (red: CH1, green: CH2, blue: CH3, black: CH4, yellow: CH5)



a) Immersive VR environment
(IVR)



b) Non-immersive VR environment
(NIVR)

Fig. 9. Brain activity spectrum in the beta frequency
Line legends: (red: CH1, green: CH2, blue: CH3, black: CH4, yellow: CH5)

large differences in the power spectrum, except for the blue trace line CH3 at the occipital region. However, as with the scalp maps shown in the previous figures, the power distribution is clearly distinct for NIVR than those of IVR.

Although the findings presented in this study are preliminary, distinct differences between IVR and NIVR not only in the power magnitudes illustrated in the brain activity spectrum, but also in the power distributions shown in the scalp maps can be recognized. Higher theta waves for IVR found in this study, are consistent with the findings of Bishchof, et.al [10] which presented evidence on the relation of theta waves and spatial navigation of humans in virtual reality environments. On the other hand, greater alpha frequency band power has also been attributed to motion sickness experienced by test subjects in study conducted by Lin, et.al. [11].

Conclusion

Preliminary investigation into the differences in the EEG features of immersive and non-immersive virtual reality environments showed distinct differences in the power magnitudes and in the power distributions on the brain activity spectrum. Immersive virtual reality environments had greater alpha as well as theta power bands compared to non-immersive VR environments.

Succeeding work requires further EEG measurements and analysis including an independent component analysis (ICA) to separate statistically independent signals from observed multi-channel signals to obtain more insight into EEG features of both virtual reality environments.

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没入型および非没入型 VR 環境：EEG の比較

マチャコン　ヘルチェル　タデュース

要約

様々な論文において，没入型・非没入型仮想現実の保健分野や医療分野における，有用性が示されている．しかし，ヘッドマウントディスプレイ等の没入型仮想現実の利用においては，副作用も報告されている．そこで，本論文では予備的な調査として，没入型と非没入型の両方の環境において，脳波検査を行った．その結果，２つの仮想現実（VR）環境における脳波パワースペクトル分布に明確な違いが見られた．

キーワード：没入型環境，非没入型環境，仮想現実，脳波，脳波パワースペクトル